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Instrumentation on the RAIDS Experiment II: Extreme Ultraviolet Spectrometer, Photometer, and Near IR Spectrometer

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13. ABSTRACT (*Maximum 200 words*)

The RAIDS experiment consists of eight instruments spanning the wavelength range from the extreme ultraviolet (55 nm) to the near infrared (800 nm) oriented to view the Earth's limb from the NOAA-J spacecraft to be launched into a circular orbit in 1993. Through measurements of the natural optical emissions and scattered sunlight originating in the upper atmosphere including the mesophere and thermosphere, state variables such as temperature, composition, density and ion concentration of this region will be inferred.

This report describes the subset of instruments fabricated or otherwise provided by the Space and Environment Technology Center (formerly Space Sciences Laboratory) at The Aerospace Corp. The companion to this report describes the instruments from the Naval Research Laboratory. The Extreme Ultraviolet Spectrograph (EUVS), the three fixed filter photometers OI (630), OI (777), and Na (589), and the near infrared spectrometer (NIR) will be described. These are all mounted on a mechanical scan platform that scans the limb from approximately 75 to 750 km in the orbital plane of the satellite every 90 seconds.

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1. RAIDS OVERVIEW

The Remote Atmospheric and Ionospheric Detection System (RAIDS), scheduled to be launched on the NOAA TIROS-J spacecraft in the first half of 1993, is designed to perform comprehensive measurements of upper atmospheric airglow emissions on the Earth's limb (see Figure 1). These measurements will be used together with state-of-the-art aeronomic models of airglow generation and transport to infer profiles of atmospheric and ionospheric constituents. The instrument complement provides nearly continuous coverage of a wide spectral range (55–870 nm) so that multiple emission features associated with each of the major atmospheric constituents can be simultaneously measured. Comparisons of density profiles for a single species derived from different emissions will be used to validate airglow modeling concepts. The inferred profiles will also be assembled into global maps which should provide new insights into the 'weather' of the upper atmosphere. Thus, it is expected that over its three year life RAIDS will supply an important data set for the advancement of the science of remote sensing of the upper atmosphere.

RAIDS is a joint venture of The Aerospace Corporation and the Naval Research Laboratory. The eight instruments which comprise the RAIDS complement are listed in Table 1 along with some of their characteristics. Seven of the eight are attached to a platform which scans their fields of view across the limb from 75 to 750 km tangent altitude. The FUV spectrograph (described in the companion paper) does not ride on the platform, but images a portion of the limb. Aerospace supplied five of the instruments and the scan platform mechanism. The Aerospace instruments are the extreme ultraviolet spectrograph (EUVS), near infrared spectrometer (NIR), and the three photometers. NRL provided the other instruments and the flight microprocessor. Figure 2 shows a photograph of the RAIDS experiment and identifies its components. This paper describes the subset of RAIDS instruments supplied by The Aerospace Corporation.

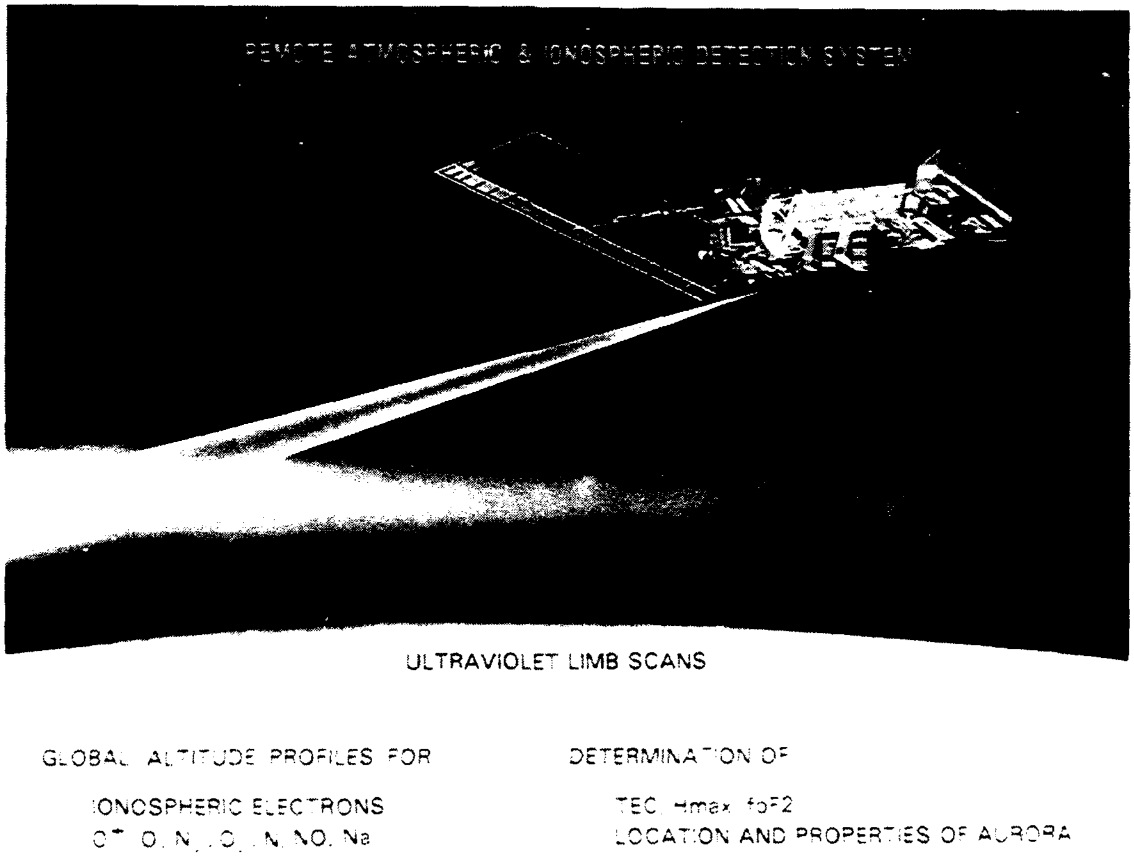

Figure 1: An artist's conception of the TIROS spacecraft with the RAIDS instrument mounted on the underside.

Instrument	Investigator	Wavelength Range (nm)	Bandpass (nm)	Field of View[a] (deg^2)	Integration Time (sec)	Peak Responsivity (counts/s/R)
EUV Spectrograph	Aerospace	55–111	1.2	0.1×2.3	0.5	0.5
FUV Spectrograph	NRL	130–170	0.8	4.0×0.1	≤ 64	2.5
MUV Spectrometer	NRL	190–320	1.0	0.1×2.1	0.025	7.5
NUV Spectrometer	NRL	295–400	0.7	0.1×2.1	0.025	1.8
NIR Spectrometer	Aerospace	725–870	0.84	0.1×2.1	0.025	0.21
589 Photometer	Aerospace	589	1.5	0.1×2.1	0.1	0.67
630 Photometer	Aerospace	630	1.5	0.2×2.1	0.1	4.4
777 Photometer	Aerospace	777.4	1.5	0.2×2.1	0.1	3.6

[a]vertical x horizontal

Table 1: The RAIDS instrument complemer

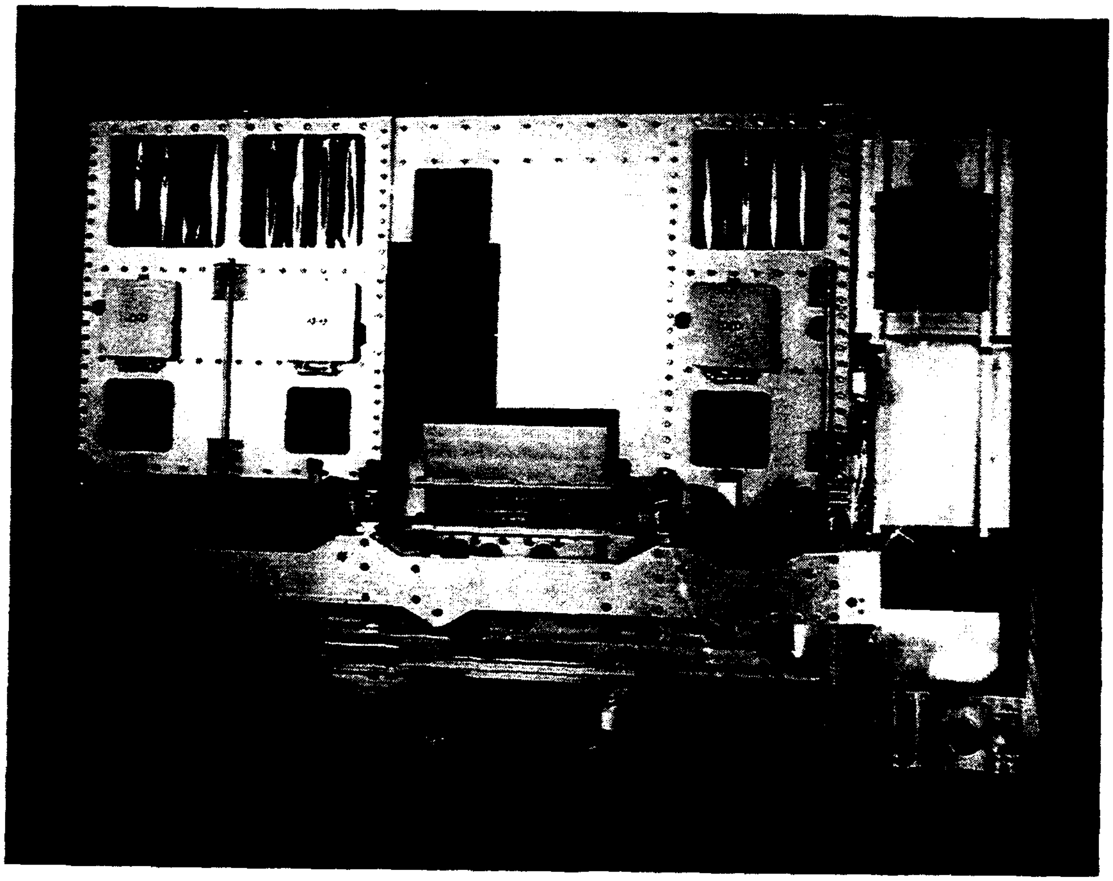

Figure 2: The RAIDS instrument is shown with the eight instrument apertures visible. The three larger apertures across the top (from left to right) correspond to the PH630, PH777, and MUV. The three smaller apertures correspond to the NIR, NUV, and PH589. The EUVS aperture is seen at the right. The aperture of the FUVS can be seen near the center of the device.

2. EXTREME ULTRAVIOLET SPECTROGRAPH

The EUVS instrument will measure many important atmospheric emissions in the extreme ultraviolet. Several of these features are identified in the upper portion of Table 2. One of the primary emissions of interest is the 83.4 nm emission of O^+.[1] This feature originates in the lower thermosphere due to ionization of atomic oxygen by the solar EUV flux and by photoelectron impact. A fraction of the emitted photons travel upward into the F2 ionosphere where they undergo multiple resonant scattering by O^+ ions. Due to this scattering process, the 83.4 nm limb emission profile takes on a shape characteristic of the F2 layer. Using a radiative transfer model it is possible to extract information on ion densities from these profiles. Other EUV emissions listed in Table 2 yield information on neutral particle densities on the dayside and ionospheric profiles at night.

The EUVS instrument, shown in Figure 3, is a f/5 near Wadsworth concave grating spectrograph. Incoming light passes through a mechanical collimator and is focussed onto a position sensitive photon counting detector by a spherical reflectance grating used in the first order. The collimator has an open aperture measuring 75 x 75 mm^2. Its transmission was measured in the visible as 30%, in agreement with calculation. The grating has a ruled area of 81 x 76 mm, a ruled density of 1710 lines/mm with a first order blaze at 70 nm and a 355 mm focal length. Overall grating efficiency is 6.1%. The instrument covers the wavelength range 55–111 nm in two segments. A motor is used to rotate the grating into one of two positions which focus the ranges 55–85 nm and 77–111 nm onto the detector. The ranges overlap so that the important 83.4 nm emission of O^+ is always observed. The spectral resolution is 1.2 nm and the field of view (FOV), defined by the collimator, grating, and detector mask is $0.1° \times 2.3°$.

The EUVS detector[2] employs a set of three bare microchannel plates in a 'Z' stack configuration and a wedge-and-strip anode. Detector quantum efficiency is 10% at 83.4 nm. Although photon position on the detector is resolved in two dimensions, the detector is used in a one-dimensional mode in which pixels in the cross-dispersion direction are summed. The output of the detector is a complete spectrum in 128 wavelength bins every 0.5 second integration period. This detector has a very low dark count rate of 2–3 counts/sec distributed over its entire surface. Anticipated count rates of important lines are on the order of a hundred or more counts/sec, so the dark rate will not impact signal-to-noise. A windowless detector is necessary for operation in this very short wavelength region. A detector door exists only to insure cleanliness during pre-launch processing. This door will be permanently opened once the spacecraft is on orbit. A month's delay between launch and door operation is planned to reduce the risk of contamination by allowing time for the satellite outgassing. All other instrument dust covers will be opened at this time as well.

Feature	Instrument	Processes	Inferred Parameter(s)
OI 61.7	EUVS	Photoionization and photoelectron ionization of O.	Dayside O
OII 83.4	EUVS	Multiple resonant scattering of upwelling thermospheric radiation created by photoionization and photoelectron ionization of O.	Dayside O^+
OI 91.1	EUVS	Radiative recombination of O^+.	Nightside O^+
OI 98.9	EUVS	Multiple resonant scattering of sunlight.	Dayside O
N_2 *BH*	EUVS	Photoelectron impact excitation of N_2.	Dayside N_2
NII 108.5	EUVS	Photoionization of N_2.	Dayside N_2
Na 589.0	PH589	Resonant scattering of sunlight.	Dayside Na
OI 630.0	PH630	Charge exchange of O^+ and O_2 to produce O_2^+ followed by dissociative recombination. Emission is quenched by N_2.	Nightside O^+, O_2, N_2
OI 777.4	NIR/PH777	Radiative recombination of O^+.	Nightside O^+
O_2 atm.	NIR	Three body recombination of O.	Nightside O
O_2 atm.	NIR	Multiple resonant scattering of sunlight.	Dayside temperature
OH Meinel	NIR	Recombination of O and H.	Nightside temperature
NO_2 cont.	NIR	Recombination of NO and O.	Nightside NO

Table 2: Some emissions to be measured by the Aerospace portion of the RAIDS instrument complement. All wavelengths are in nanometers. Many emission scale heights can also be used to determine exospheric temperature.

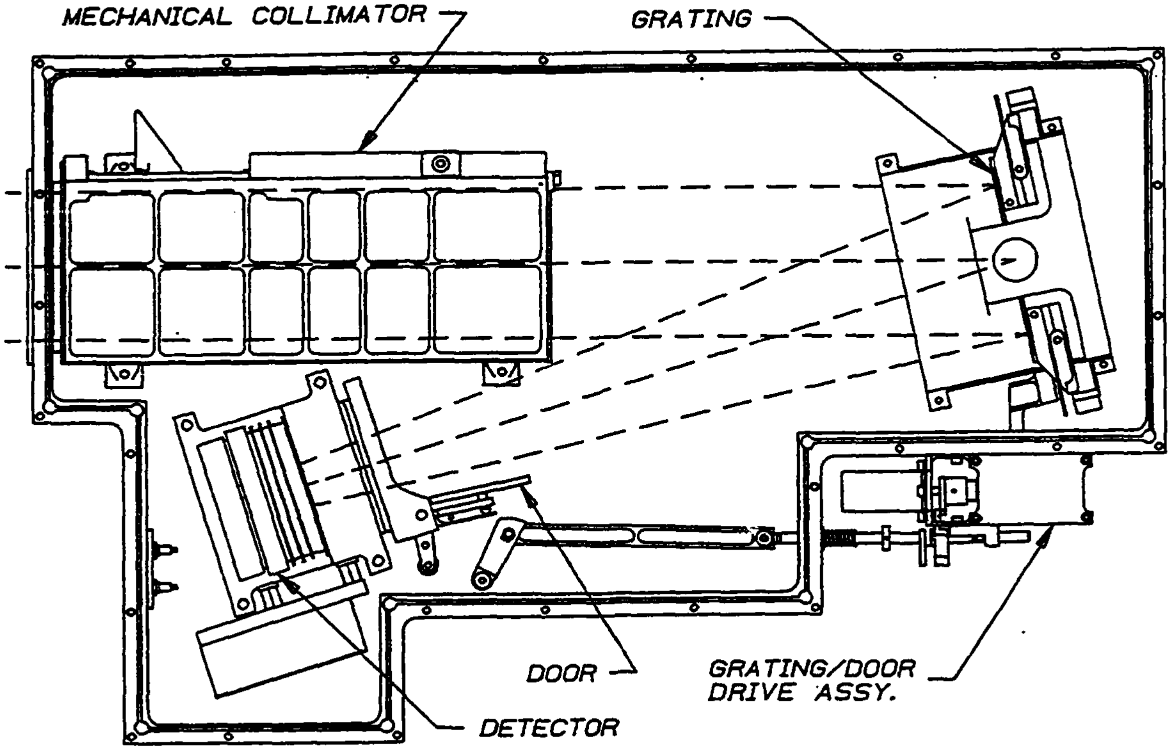

Figure 3: Configuration of the RAIDS extreme ultraviolet spectrograph.

Calibration was performed under high vacuum using a diffusing screen and calibrated transfer detector. The diffusing screen was an aluminum plate which had been bead blasted and coated with 150 Å of platinum. This screen, when illuminated by the EUV light from a monochromator/gas discharge system, provided a source of relatively uniform brightness for calibration of the EUVS. A channeltron detector was used as the transfer detector. A small mechanical collimator and mask attached to the channeltron defined its field of view. This detector was first calibrated relative to a National Institute of Standards and Technology (NIST) photodiode. The channeltron was then used to measure the uniformity of the diffusing screen. A screen section of sufficient uniformity was selected and the EUVS instrument was masked to view only that section. The placement of the EUVS behind the mask was varied so that different sections of the aperture were illuminated. Using this technique, the EUVS response across its aperture was determined to be uniform to within 10%. Comparison of aperture averaged EUVS and transfer detector measurements of the screen yielded the absolute calibration of the EUVS. The incident beam was monitored for stability throughout the calibration procedure using the NIST photodiode. The anticipated responsivity may also be calculated as

$$R = \frac{10^6}{4\pi} A\Omega T\epsilon Q_e, \tag{1}$$

where A is the aperture area, Ω is the solid angle viewed, T is the collimator transmission, ϵ is the grating efficiency, and Q_e is the detector quantum efficiency. Figure 4 compares the measured and calculated EUVS responsivity as a function of wavelength. Residual uncertainties in the measured values are roughly $\pm15\%$ resulting from a combination of uncertainties in the NIST diode calibration and EUVS counting statistics during calibration.

3. NEAR INFRARED SPECTROMETER

Table 2 shows some emissions which will be observed by the NIR spectrometer. One feature of interest is the O_2 atmospheric band system. At altitudes above 95 km the parent state of this emission is excited primarily by collisional quenching of $O(^1D)$ by O_2. The shape of the (0,0) band spectra can be used to infer the O_2 rotational temperature,[3] which is equal to the kinetic temperature of the atmosphere. Thus, observations of these emissions can be used to determine dayside mesospheric temperatures. It may also be possible to infer information about atomic oxygen densities from measurements of this band system at night.

The NIR spectrometer (see Figure 5) is an f/5, 125 mm focal length Ebert-Fastie monochromator employing off-axis spherical mirrors. The grating has a ruled area of 25 x 25 mm^2, is ruled at 1800 lines/mm with a first order blaze at 750 nm, and has an efficiency of 40%. Wavelengths within the 740–870 nm range may be selected with 8.4 Å resolution by rotation of the planar grating. The detector used is a photomultiplier with a GaAs photocathode

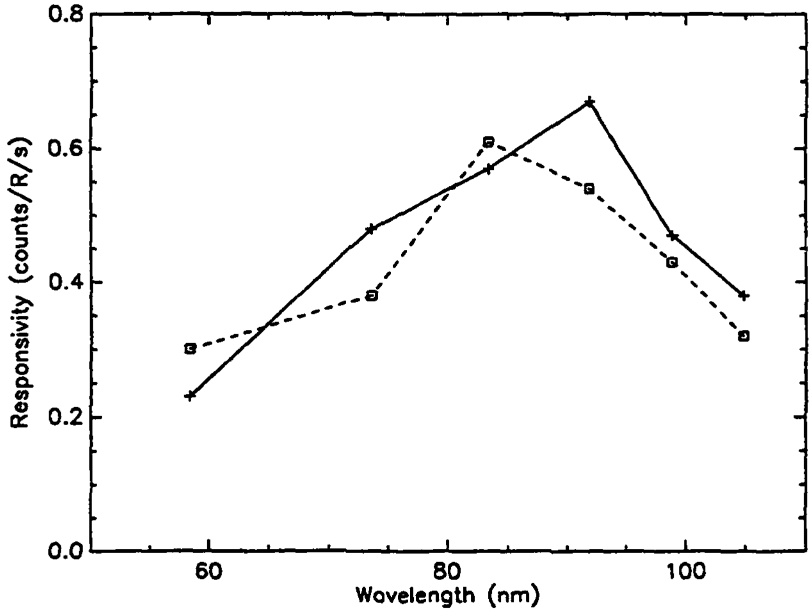

Figure 4: Measured (solid curve) and calculated (dashed curve) EUVS responsivity as a function of wavelength.

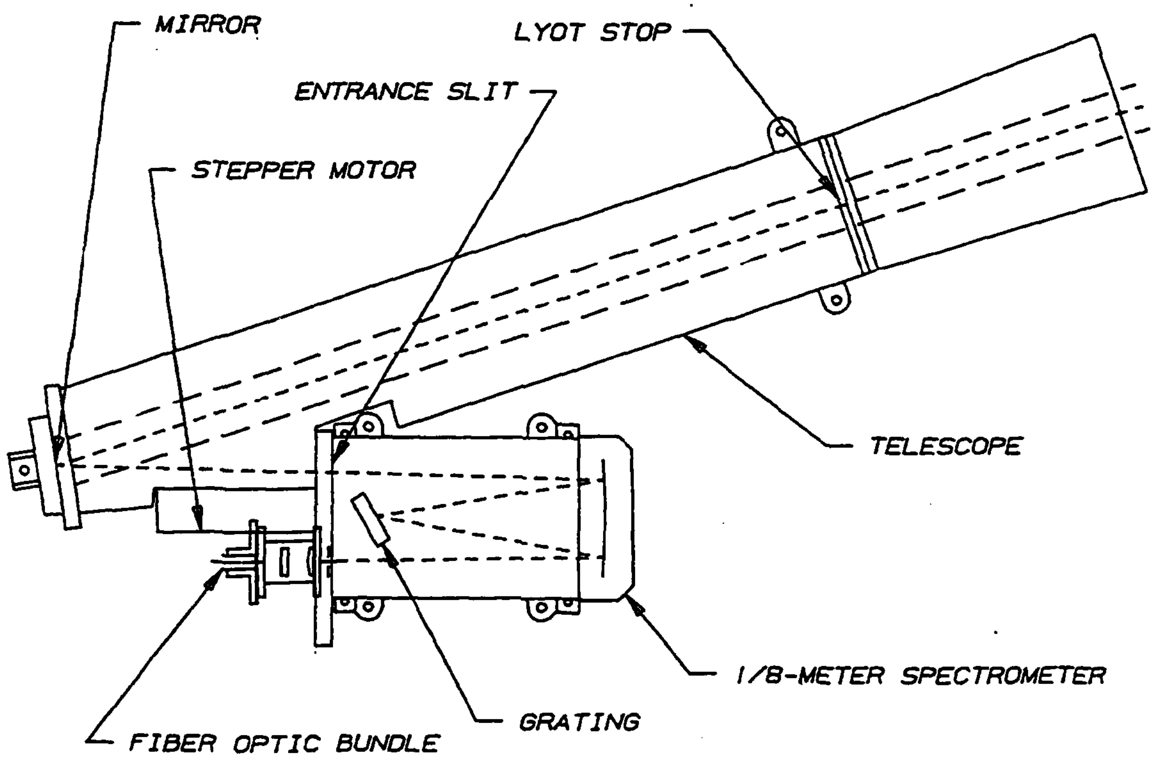

Figure 5: The RAIDS near infrared spectrometer.

and glass window with a quantum efficiency of 12% at 750 nm. This detector must be cooled to reduce the dark count to a reasonable level. For this reason the photomultiplier is housed in a box which is independently mounted on the spacecraft and radiatively cooled to approximately -20 C. Dark count rates at this temperature are roughly 20 counts/sec. The monochromator signal is delivered to the detector box by a 3 mm diameter fiber optic bundle. A lens assembly couples light from the monochromator into the bundle.

There are two modes of operation for all three spectrometers in the RAIDS payload including the NIR spectrometer. The predominate operating mode will be a limb scanning mode. In this mode the scan platform is in motion while the NIR spectrometer grating is fixed at a particular wavelength. This provides an altitude profile of radiance for one emission feature. The flight microprocessor can be programmed to command the NIR to change wavelengths between altitude scans (during scan platform flyback) so that alternating scans are performed at different wavelengths. Up to three arbitrary wavelengths may be cycled through in this fashion.

A second mode of the RAIDS experiment allows for complete NIR spectra to be obtained with the scan platform pointing at a fixed tangent altitude. It takes roughly 25 seconds for a complete cycle of the grating. In this mode the scan platform can be programmed to alter its look angle in between spectrometer scans. A series of up to 16 arbitrary platform look angles can be so programmed.

Calibration was performed by illuminating the instrument with a diffuse white light source of known brightness and recording the response at 20 intervals throughout the wavelength range. The responsivity of the NIR spectrometer as a function of wavelength is shown in Figure 6. Accuracy is 5–10% with uncertainties primarily due to the calibration of the transfer source. The instrumental profile was measured at 760.1 nm using a stable line source. This is shown in Figure 7.

Of particular importance to obtaining good limb profile measurements in the near infrared is a high level of off-axis rejection. While the telescope assembly is well baffled to control scattered light, careful measurements of the field of view determined that the geometry near the entrance slit contributed appreciably to a residual off-axis signal. By modifying and blackening this area the rejection was substantially improved. The resulting off-axis response is shown in Figure 8. This measurement was made using two separate detectors due to the large dynamic range involved. The area on the left side of the plot corresponds to the earth side of the field of view.

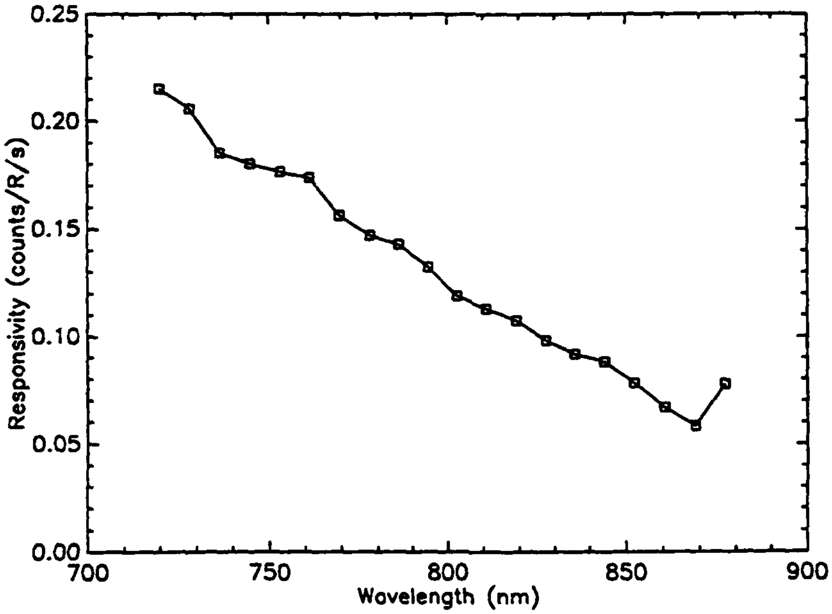

Figure 6: Photometric responsivity of the NIR spectrometer.

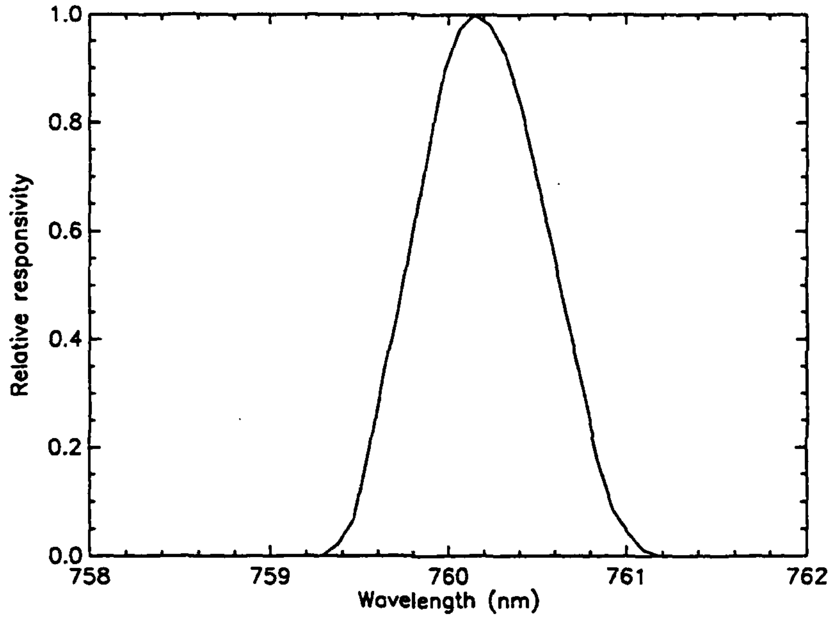

Figure 7: Instrumental profile of the NIR spectrometer.

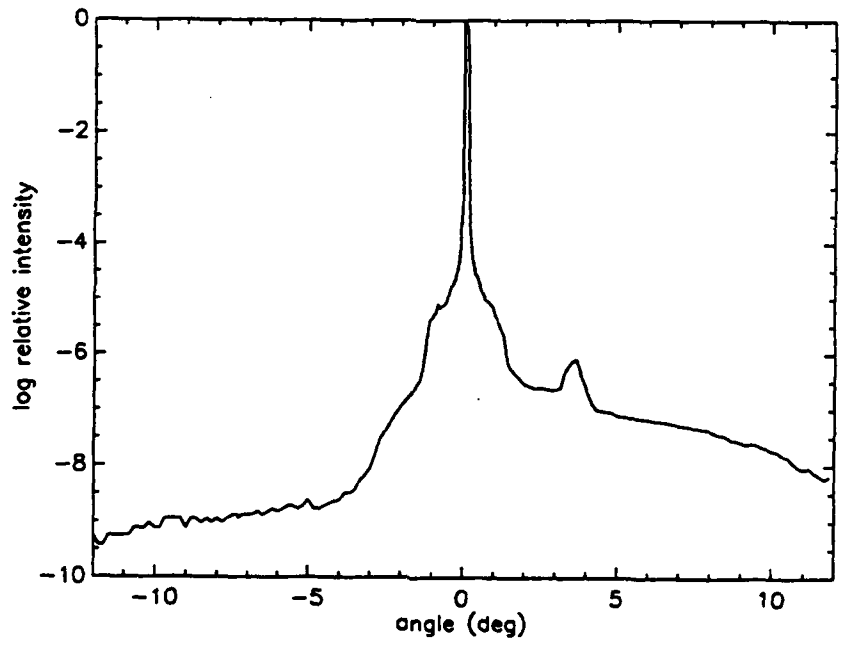

Figure 8: Off-axis rejection characteristic of the NIR spectrometer.

4. PHOTOMETERS

The characteristics of the emissions measured by the photometers are shown in Table 2. The 589 photometer monitors atmospheric sodium. This measurement provides a secondary means to determine the tangent altitude since the sodium layer is known to be localized near 95 km. The OI (630 nm) emission is an important feature of the nightglow resulting from dissociative recombination of O_2^+.[4] Because O_2^+ production is primarily due to charge exchange of O^+ with O_2, this emission is related to the product of the densities of these latter two constituents. Additionally, the emission is quenched by N_2 at low altitudes, providing information on the molecular nitrogen density. The 777 photometer also measures a nightside emission — that due to recombination of O^+. This feature will provide an important check on O^+ profiles derived from related emissions in the extreme (91.1 nm) and far ultraviolet (see the companion paper). The 777 photometer is roughly 15 times more sensitive than the NIR spectrometer at this wavelength.

The three RAIDS photometers (see Figure 9) are all of a similar optical design. The 589 employs a 1/8 meter off-axis telescope identical to that used by the NIR spectrometer. A slit in the focal plane acts as a field stop and defines the field of view to be 0.1° × 2.1°. The telescope aperture is 21 × 25 mm. The 630 and 777 photometers use 1/4 meter telescopes, 0.2° × 2.1° fields of view, and 42 × 50 mm apertures. Filters used in the photometers have a transmittance of 75% and a bandpass of 1.5 nm. Like the NIR instrument, the photometers all employ GaAs photomultipliers which require cooling. These tubes are housed in the same detector box as the NIR detector. After passing through the appropriate interference filter, light is focused onto a 3 mm diameter optical fiber bundle which transmits it to the detector box. Like the NIR, the photometer telescopes have been optimized for off-axis rejection.

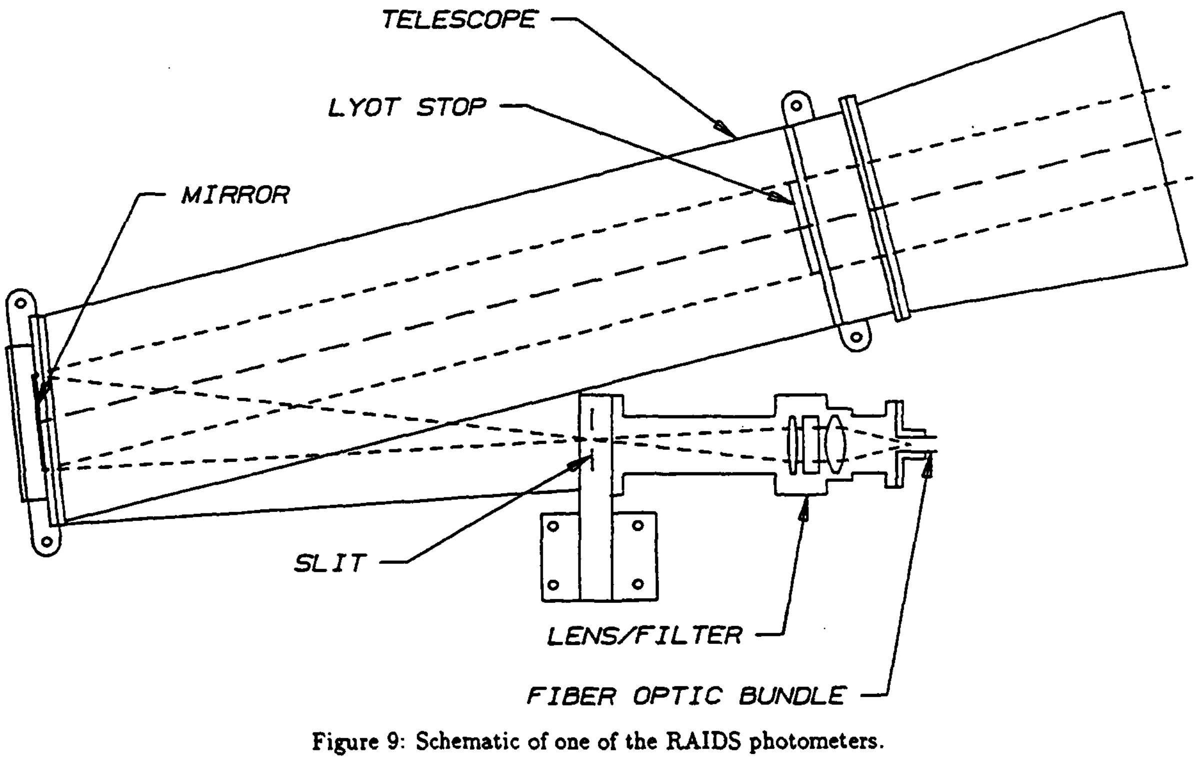

Figure 9: Schematic of one of the RAIDS photometers.

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